Final Specialist Report for the Malheur Invasive Plant Treatment DEIS

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Soil Resource Report

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September 22, 2013

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Introduction

The effect of invasive plant treatments on soil and water is a primary public issue. There was concern that herbicides may accumulate in soils and harm soil biology, nutrient cycling, and the organisms necessary for decomposition and soil productivity.

The action alternatives address the unintended consequences of the using herbicides, manual, mechanical and cultural methods to control invasive plants. Invasive plants are recognized for the potential to interfere with plant communities and altering below ground processes, especially in rangelands. This report addresses the trade-offs from the alternative approaches versus the impact weeds have on natural soil and plant communities if left un-checked.

Soils regulate the fate of herbicide through soil properties. The soil litter and medium itself controls the persistence and chance for herbicide to either percolate or runoff to non-target areas. This analysis addresses the fate of herbicide within soils considering the unique environment conditions of the Malheur National Forest and site-specific characteristics. Factors other than taxonomic soil type usually determine the fate of herbicides within the soil, such as of groundcover, compaction, gradient, and biological capacity. Biological capacity is the ability of soil organisms to decompose litter and relates directly to fertility. Higher amounts of organic matter, water, light and favorable temperature affects the ability of soil organisms to process vegetation and herbicide residue.

Overview of Issues/Elements of the Purpose and Need Addressed

The analysis focuses on herbicide application since this is the highest risk of the proposed actions. The analysis addresses the particular public concern regarding accumulation risk to soil biological function using the measures below:

- Plausible exposure scenarios where herbicide use may harm soil organisms and thus soil nutrient production
- Qualitative assessment about the effectiveness of project design features to prevent harm to soils.
- Herbicide fate depending on soil properties

Affected Environment

Existing Condition

Soil conditions influence the risk for invasive plant spread by creating suitable habitat where these colonist species can dominate. Sites that favor weed spread include habitats such as roadsides, parking areas, and natural habitats that have altered characteristics from disturbances such as forest clearing or wildfire. Disturbed soils have higher levels of available nutrients and exposed soil and open light conditions, which invasive plants can quickly utilize (Williamson and Harrison 2002, James et al. 2010). Invasive plants, almost by definition, have traits that allow for quick uptake of nutrients, growth and prolific seeding (Sutherland 2004). Frequent disturbance, such as road clearing along a highway, perpetuates primary succession conditions that favor colonist plant traits which most invasive plants have. Once established, there is evidence that the persistence of invasive plants accompanies shifts in underground resources (Ehrenfield 2003, Steinlein 2013).

The invasion and persistence of invasive plants can also be attributed to biological reasons. Almost all plants experience positive and negative feedback from soil microbes (Wolf and Klironomos 2005, Steinlein 2013). However, at the current stage of invasion for the US, most successful invasive plants appear to make use of positive win win affiliations with soil microbes and lack the negative pressure from soil predators (Kulmatiski et al 2008, Steinlein 2013).

Since weeds have plant traits to quickly uptake nutrients, they are strong competitors in favorable growing conditions. Disturbance produces pulse nutrients that match the high uptake capacity of invasive plants. In contrast, natural environments, in particular the semi-arid dry grasslands, have low available resources with native plants adapted to survive in marginal conditions (James et al. 2010). On this type of playing field, intact vegetation provides considerable biotic resistance against invasive plants (James et al. 2010). In studies along roadsides, intact forest habitat was effective resistance for invasive plants establishing despite dispersal well into the canopy (Flory and Clay 2009, Buonopane et al 2013). Similarly, in southern Utah where water and nutrients pose extreme limitations on plant growth, invasive plants prevailed in the most fertile environments (Bashkin et al. 2003). This finding was further documented in the roadside survey that found fewer invasive plants adjacent to roads crossing arid desert with biological soil crusts compared to more mesic open grassland scrub (Gelbard and Belnap 2003).

Though desert and semi desert habitats limit the invasion of weeds, the colonist plant traits enable weeds to endure marginal sites once established. Since most invasive plants can respond quickly to nutrients, this strategy enables these plants to take advantage of wet years. Invasive plants may persist in marginal growing areas with dormant seed and then geminate and spread during wet years. In studies of spotted and diffuse knapweed, the spread of the invasive plants was suppressed during drought years whereas wet years showed large population increases (Suding et al 2004, D. Pearson, personal communication). Abiotic influences of moisture and temperature create sideboards for invasive plant survival, though somewhat variable by species. A shortened growing season in high elevations and cold dry condition in the high desert inhibit spread of invasive plants.

In analyzing the site data on the Malheur NF, the distribution of invasive plants shows climatic limits. Across the Malheur NF, invasive plants occupy more acreage in the northern and western forest area where high available moisture and moderate growing temperatures prevail. In contrast, much lower distribution of weed sites occur in the southwestern quarter where the climate is cold and dry. Similarly, when correlating sites with elevation, most weed sites do not exceed 6,000 feet where the short growing season becomes limiting. The abundance of invasive plants may not be an artifact of survey since the density matches that of the adjoining Wallowa Whitman NF. It's acknowledged the mesic conditions correlate with higher timber production and thus increased density of roads.

Disturbance and weeds - Soil Conditions within Treatment Areas

Forest activities and natural disturbance events alter ground conditions by displacing vegetation along with exposing bare ground and ramping up nutrient cycling, creating ideal conditions for invasive plants. Novel environments such as rock pits, constructed parking areas or compacted drives, create un-natural circumstances that mimic primary succession – a condition that will always favor invasive plants (Seastedt et al 2008). The disturbance itself may be a recent event (Seastedt et al 2008, James et al 2010) or from legacy impacts of past management even up to 100 years past (Norton et al 2007, Rinella et al 2009). The degree of disturbance and frequency dictates how long a site may be suitable for invasion. However, the potential for invasive plants to establish depends on the introduction of weed seeds and plant parts, considered propagules

(Flory and Clay 2009, Birdsall et al 2011). Thus, risk for weed invasion in disturbed sites is a combination of degree of disturbance and chance for introduction from outside vectors (James et al 2010).

The action of turning, clearing, and displacing soil amplifies the level of nutrients similarly to turning a garden bed. The physical action of churning soil aerates and increases the available carbon that subsequently amplifies the biological activity that produces mineral nutrient forms. In experiments displacing soil and forest floor in forests, higher production rates are reported for mineral forms of nitrogen (Guo et al 2004, Booth et al 2006) which is one of the limiting plant nutrients in the forest. The level of nutrients can remain high for years or fluctuate seasonally depending on adequate water soil organisms rely on. For example, on re-contoured roads in northern Idaho, nutrient levels were significantly higher in the first year compared to natural areas; however, by year ten the decommissioned sites had abundant trees, shrubs and understory plants with available nutrients down to levels of adjacent natural areas (Lloyd et al 2013).

The lifeforms of weeds considered noxious on the Malheur NF fall into two broad categories: (1) annual and perennial forb species and (2) annual grasses. Scotch broom, an invasive shrub, has limited occurrence in this dry habitat, preferring higher moisture and cool conditions on the west side Cascade forests. Forbs, which make up most the invasive plants on the Malheur NF, use a tap root that mines a greater depth of soil to acquire water and nutrients than grasses (Kulmatiski et al 2008); shrubs have an even greater capacity to draw from deep soil. Annual plants such as the annual grasses do not penetrate deep into soil, but grow quickly during ample moisture and when nutrient levels are high (Eviner and Firestone 2007). Thus, these plants have high propensity to grow on disturbed areas where water holding capacity and organic matter levels are low for most the year except during the short nutrient burst periods when moisture and cold temperature is not limiting.

The majority of the invasive plants on the Malheur NF have strong affinity to open light conditions and low shade tolerance. Thus, a strong correlation exists for weeds in recently deforested areas, road corridor openings and open rangelands. The low shade tolerance of most the weed species found on the Malheur NF is evident in studies in the Rocky Mountains and Eastern Washington. Studies of edge environments found substantial drops in weeds moving away from major roadways in shaded environments (Hansen and Clevenger 2005, Pauchard and Alaback 2006, Buonopane et al 2013). The central Washington study found that weeds, many common to the Malheur NF, on average did not penetrate farther than 10 meters (32 feet) from the roadside where a forest canopy existed (Buonopane et al 2013). Similarly, a Canadian study in eastern front Rocky Mountains observed substantial decrease in weeds 10 meters from a roadway in a forested environment as compared to 150 meters in a rangeland environment. Field observations in the Malheur NF had a similar trend.

The current documented infestations cover roughly 2,124 acres on the 1.7 million acre project area. As found elsewhere, the primary sites for weeds include roads, recreation sites, waterways and areas where active management disturbs soil such as skidtrails, burn piles and cattle troughs. The dataset shows weeds grow mostly along the disturbed road corridors and have less abundance on adjacent natural habitat. Field observations found weeds readily spread to adjacent land where the area has some level of disturbance – typically from bared soil from clearing or grazing vegetation. Figure 1 shows the weed site type risk for dispersal in descending order.

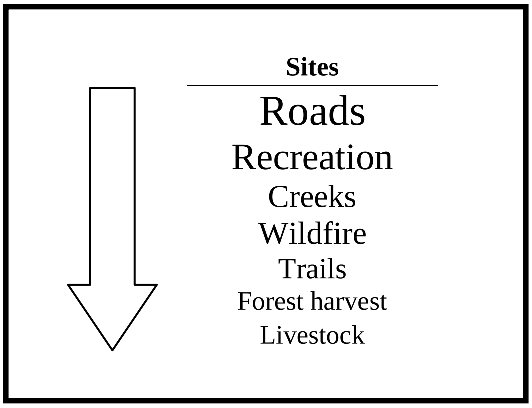

Figure 1. Vectors for weed spread.

Disturbances that can be subject to weed invasion vary in frequency and intensity (James et al 2010). A forest fire that burns at high and moderate severity can completely eliminate the overstory and understory plant canopy and bare soil. The combusted organic material leaves a high nutrient load. Though the disturbance has high intensity, the spike in nutrient load and amount of exposed bare soil decreases rapidly within five years as the native vegetation re-colonizes the site and the risk of weed invasion declines. In contrast, livestock grazing occurs every season. The scale of the disturbance is much less than a wildfire since grazing exposes a fraction of soil area compared to wildfire; the intensity of the grazing is concentrated at gathering areas rather than across tens to thousands of acres. As a means to display the variable risk for invasion across the Malheur NF, Table 1 lists events that can impact the area by their frequency and intensity coupled with exposure to invasive weed seeds and plant parts. The desired vegetation reflects the land suitability.

Table 1. Risk for invasion by disturbance frequency, intensity and propagule pressure from invasive plants.

Forest activity or natural event	Disturbance Frequency/ intensity	Propagule pressure	Desired vegetation	Site types
Recreation (other than road use)	Perpetual/ Low	High	Un-natural surface	Dispersed and developed sites; campgrounds, hunter camps, trailheads
Road maintenance, construction highways, main system roads	Perpetual/ High	High	un-natural surface stabilized by vegetation cover desired.	roads, rock pits (quarries)
Livestock grazing	Seasonal/ Moderate	Mod	Range improvement, productive landbase	Dry open grassland steppe, shrublands, dry forestlands
Vegetation management (thinning, brushing, logging, prescribed burning)	Periodic/ High (yarding corridors, landings, burn piles)	High	Forest vegetation, productive landbase	Dry and mesic forestlands
Wildfire and incident response	Periodic/ High	Mod	Forest and rangeland	Dry and mesic forestlands

Forest activity or natural event	Disturbance Frequency/ intensity	Propagule pressure	Desired vegetation	Site types
			vegetation, productive landbase	
Closing roads	Periodic/ Low	Mod	un-natural surface stabilized by vegetation cover desired.	Natural surface or non-essential roadways
Restoring roads and landings	One time/ Low	Mod	Stabilized site, naturalized vegetation	Decommissioned roads and landings
Adjacent agriculture	Perpetual/ High	Mod	Cultivated crops	Valley floors and terraces
Stream Restoration (fish passage and habitat projects, riparian vegetation restoration)	Seasonal/ High	Low	natural surface, stream channel, riparian vegetation cover	Alluvial floodplain of streams

Roads and rights of way have the highest incidence for invasive plants invasion from perpetual disturbance together with a constant seed source from passing traffic (Zouhar 2008, Birsall et al. 2011). The open light conditions inherent to roads creates ideal habitat since most weeds on the MNF do not tolerate shade. The road disturbance footprint has gravelly road fill emplaced next to dugout ditches, and bared cutslopes, open sites for weeds to establish. Roadways and railways fragment the landscape, creating edge environments where weeds can thrive (Hansen and Clevenger 2005).

Road management and the vehicle traffic serve to spread weeds. Weeds are found where vehicle traffic congregates at recreation areas, parking lots and where forest management activities concentrate at log landings. Road maintenance activities are known to spread weeds from mowing and grading activities. Transplanted road materials from infested rock pits may carry weed seeds and plant parts into more remote locations of the forest.

Roads vary for risk of weeds depending on the level of construction. A four wheel drive two track has much less potential for sustaining weeds compared to a high level construction highway. The construction footprint extends from the roadside to the edge where the natural vegetation dominates. Typically, the edge of the roadcut demarcates the change when roads cross forests. Gelbard and Belnap (2003) documented an average 14 meter (50 feet) novel vegetation width along paved roadways compared to an only 2 meter (6 feet) width along 4wd two tracks (Figure 2). The large unique vegetation span along the paved road coincided with the placement of fill and excavation. When comparing level of exotic plants, the researchers found a four time increase in cheatgrass along the paved roads versus the two track. A paved road also sheds water more effectively than low bermed primitive roads, creating high water and nutrient availability for exotic plant growth. Other authors report changes away from weedy roadside vegetation at an average 30 meters (98 feet) in Illinois (Flory and Clay 2009) and 10 meters (32 feet) in east slope Washington (Buonopane et al 2013) for forests along major roadways.

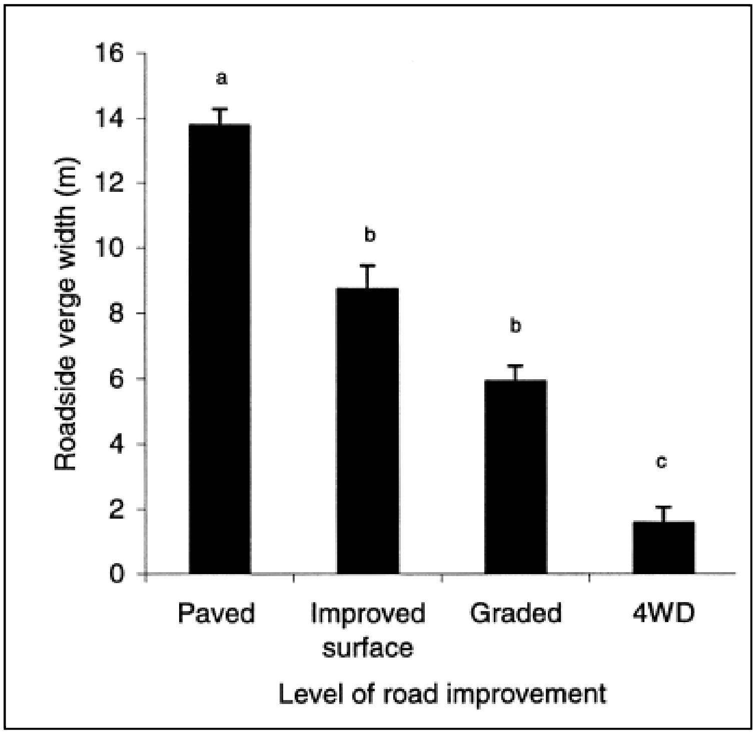

Figure 2. Roadside vegetation width that differs from adjacent natural vegetation from Gelbard and Belnap (2003) study in southern Utah. The superscripts indicate where significant differences found.

Streams have annual disturbance from fluctuating streamflow. Snowmelt flush bares stream edges leaving gravel bars and silt that is primary succession habitat. Weeds can easily occupy these sites, but the mesic conditions and well adapted riparian vegetation readily compete to re-occupy these sites. The riparian vegetation forms a type of biotic resistance that damps the spread of weeds. The seed dispersal of weeds is periodic, and dispersed by streamwater, birds and animals along the riparian corridor.

Grazing lands experience annual disturbance from livestock along with intermittent vehicle use that can bare soils in livestock congregation areas near troughs, salt licks, fences and water ways. Plant parts may stick to animals and be transported into rangelands. The grazing activities on the MNF result in overall moderate level of disturbance and occur within a timeframe of less than six months per year. The moderate level corresponds to the small and distributed amount of disturbance across the allotment.

Vegetation clearing from fuels and logging activities disturbs soils from log yarding. Temporary transportation routes result in severe disturbance but lack annual traffic. The initial soil mixing from logging activities can lead to short term increases in nutrient release (Booth et al 2004). The available nutrients on these disturbed skid trails and lack of competing plants create ripe conditions for invasive plants to spread. The sites remain open to infestation while native understory and overstory vegetation re-occupy the site in the initial period after logging for 1 to 3 years. However, the propagule pressure from vehicle traffic is limited to the logging activity.

Burned areas have conditions that favor noxious weed spread by eliminating competing plants and bolstering the nutrient availability (Zouhar 2008, James et al 2010). The initial nutrient flush is a result of the thermal decomposition of burned vegetation combined with the subsequent further decomposition and release of nutrients by soil organisms (Hart et al. 2005). These conditions create extremely high invasion potential a few years following fire, but risk decreases over time as native vegetation recolonizes and nutrient levels drop (Zouhar 2008). Places of high heat from heavy fuels burning may favor invasion by Canada thistle and bull thistle. During field survey of the Malheur NF weed sites, Canada thistle was found to colonize old burned pile scars; the thistle has high tolerance for the alkaline and poor soil conditions associated with these severely burned areas (Korb et al. 2004, Meyer 2009).

In burned areas, the risk for weed infestation decreases with time much like after timber harvest. The initial disturbance has much traffic from fire suppression followed by rehabilitation and possible salvage activities. Although, wildfire typically results in a much higher intensity disturbance than timber harvest from complete combustion of forest and shrublands during very dry hot conditions.

Prescribed fire results in low intensity burning that retains vegetation generally across 85% of the forest floor and leaves less than 15 percent soil cover. These are default values used in the Forest Service Water Erosion Prediction Project's Disturbed WEPP application. Increased nutrient pulses result from 1 to 2 years (Hart et al. 2005) but less disturbance creates an overall low risk for invasion.

Feedback between weeds and soil

Two factors appear to determine the persistence of weeds on a site for the Malheur NF. Weeds may change the nutrient timing and magnitude through shifts in litter. The second factor is subtle and relates to biological feedback between plants and soil microbes. Over time natural predators in the soil may adapt to prey on the weeds and begin to suppress their growth. Just as with biological control with insects, the Agriculture Research Station (ARS) is pursuing this line of thinking by isolating strains of naturally occurring fungus and bacteria that suppress cheatgrass (Meyer et al 2010, Dooley and Beckstead 2010).

The feedback between weeds and soil is positive where weeds self-promote. Once established, invasive plants may increase available nutrients to perpetuate favorable conditions. It's assumed that where these species dominate, especially in monocultural stands, then the below ground effects will be more extreme. Turnover rates from easier to decompose litter and roots may increase to 50 to 120 percent. The observed effects of these invasions relevant to the Malheur NF vegetation communities include an increase in the timing and amount of available nitrogen for cheatgrass (Hawkes et al 2005, Norton et al 2007) and higher phosphorus in knapweed stands (Lejeune and Seastedt 2001). When testing the effect of nutrient limitation on diffuse knapweed in California grasslands, Suding et al. (2004) reported low phosphorus was key to lowering its competitiveness but nitrogen did not appear limiting.

The subsequent shift in nutrients from the invasion of annual grasses onto perennial grasslands and chaparral is perhaps one of the classic examples of positive feedback (D'Antonia and Meyer 1992, Eviner and Firestone 2007), considered an "invasional meltdown" (Steinlein 2013). The annual grasses create a boom/ bust cycle throughout the fall/spring wet period with the combination of quick seed set and subsequent die-off. The fall wet-up induces germination where plants grow dense, and thin out. Seed rates average 60,000 per square meter and 90% germinate during the fall onset of moisture (Eviner and Firestone 2007). Annual grasses quickly respond to available nitrogen (N) during the initial fall wet-up and scavenge nitrogen better than competing plants. Each die-off triggers a new pulse of nitrogen supply since these annual grasslands are nitrogen poor and the annual grass litter holds much of the above ground nitrogen. Where soils have a larger supply of organic matter and a diverse plant assemblage, the effect is dampened.

Thus, the ability for weeds to affect changes in the soil community depends on the site. Dassonville et al (2008) found invasive plants increased soil resources on poor sites but not on fertile sites. A study in western Montana found a temporary incursion of cheatgrass corresponding to the availability of nutrients (Gundale et al 2008). In an open savannah pine community with bunchgrasses, the researchers investigated the ringed growth of cheatgrass within the driplines of pine trees after prescribed fire. They found the cheatgrass growth corresponded to increased available nitrogen and phosphorus after fire. In unburned conditions, the grassland had limited available phosphorus and the tree dripline area had limited available nitrogen. The cheatgrass decreased after 5 to 10 years as the pine litter accumulated around the trees which lowered available nitrogen.

Weeds perpetuate growth on a site indirectly by changing the vegetation cover. Total vegetative cover can be reduced on weed infested sites where strong invaders out compete native vegetation. The presence the strong invader, spotted knapweed, can lower the prevalence of native perennial forbs and grasses (Ortega and Pearson 2005). In heavily invested sites by single stemmed invasives, this shift in plant functional type leads to more exposed mineral soil on the surface with higher evaporation (Lauenroth et al. 1994, Olson 1999) and runoff (Lacey et al 1989).

Invasive plant survival depends on feedback between soil microbes. Eighty to ninety percent of all plants depend on mutual relationships with soil microbes to survive (Steinlein 2013). Mycorrhizal fungi link with plant roots to extend the rooting network and increase nutrient acquisition. By and large these form positive, win win relationships for fungus and plant (Ehrenfield et al 2005, Kulmataski et al 2008). Many of the invasive species on the Malheur NF link to soil fungi networks for increased water and nutrient supply. Forb type species are thought to form mostly positive relationships with soil microbes while grasses may have higher predation due to abundant fine roots that attract predators (Kulmataski et al 2008).

The negative feedback from soil predators on spotted knapweed was demonstrated in a growth study by Ragan Callaway of the University of Montana (Callaway et al 2004). The researchers found that spotted knapweed had reduced growth when grown in “home” soil from Europe. The thought was that spotted knapweed had both positive and negative impacts from soil microbes. Growth experiments using fungicide to eliminate the effects of fungal microbes showed a 166% increase in spotted knapweed growth in the home soil compared to only a 24% increase in the western US soil. Thus, the researchers concluded higher negative feedback exists where plant species and soil microbes co-evolved. The current thought is that the AM-fungus forms readily with invaders and that soil predation is slower to evolve (Steinlein 2013).

Soil types and biophysical relationships

Soils and climate conditions provide broad sideboards where the highest incidence for invasion may occur. The over-riding variable may be the occurrence of un-natural constructed surfaces such as parking areas and roadsides, but climatic and abiotic influences define the invasion risk for natural habitats. Available water, the length of growing season, and soil fertility relate to potential invasion in addition to the resiliency of the plant community to rebound after disturbance. Fertile soils have stronger rebound, such as along riparian corridors after disturbance. Once established, weeds can prevail in these conditions although the native plants have strong competitive pressure. Shallow soils, or poor growth areas, will have slow growing native species. Disturbance on these marginal areas has potential for select weed species to establish since regrowth by native species can be slow, creating a longer window for weeds to invade.

Average climate data was derived for the weed sites using minimum temperature and annual precipitation from PRISM 30 meter grid data (Daly et al 2008). The lower bound of temperature serves as a gross sideboard for the climatic envelope of the various weed species. Species' range vary individually, but the number sites gives a first approximation on the areas where weeds persist. Most of the listed invasive plants occur above a mean minimum temperatures of 28 degrees Fahrenheit whereas areas on the forest have annual minimum temperatures down to 23 degrees Fahrenheit. Weeds tended to grow in annual precipitation ranges from less than 10 inches on up to 45 inches. The upper end precipitation limit may be function of cold temperatures. When querying the weeds against elevation, the abundance of weed infestations declines above 6000 feet (Figure 3). Translating into growing season length using the dominant soil series of the Malheur NF, weeds tend to establish in areas with 54 to 85 frost free days.

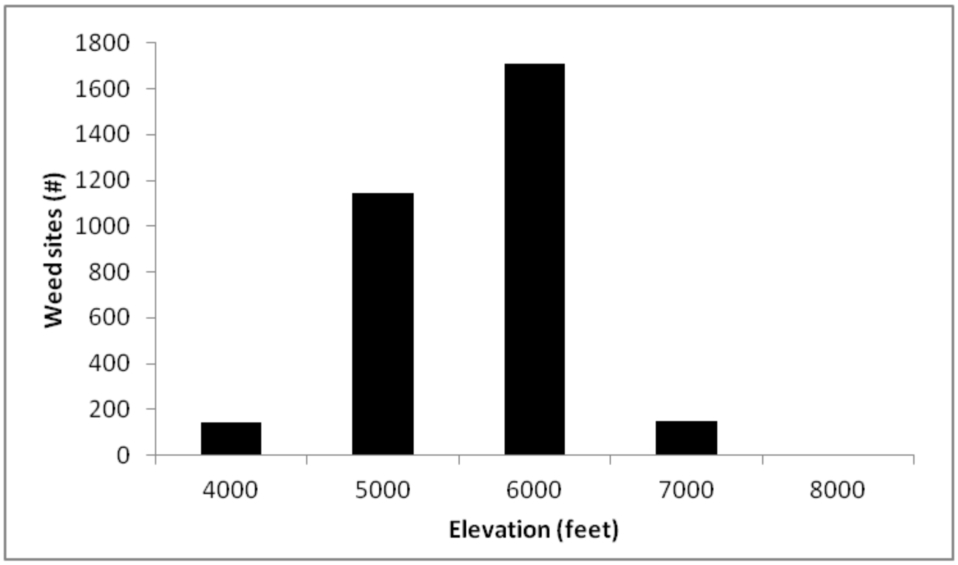

Figure 3. Weed sites by elevation.

Abiotic controls from soil types as a reflection of slope position and geologic parent materials also inform the invasion risk of noxious weeds. Generally, sites high enough in elevation with adequate moisture support closed forest environments that have less prolonged risk for invasion since the MNF regrows quickly after disturbance. The ash influence that increases water holding capacity on these sites increases the regrowth of all plants: weeds and competing native forest vegetation alike. The northern Blue Mountain and Prairie districts have the thickest accumulation of volcanic ash on the Malheur National Forest (Soil Resource Inventory, Carlson 1974). Open dry grasslands, sage steppes and meadowlands have a high risk for invasion from open light conditions as well as having similar habitat characteristics as the Eurasian homelands for many of the listed noxious weeds. Soils in these areas have mollic conditions which reflect the accumulated organic matter belowground from fine rooted perennial grasses and forbs. This organic matter enhances fertility and improves water holding capacity.

Soil fertility can be broken down into dynamic and inherent soil properties. The dynamic soil properties reflect near term changes from moderate disturbance to the active soil layer organic matter where most belowground biologic activity occurs – either forest floor or topmost mineral layer. Inherent properties derive from the eroded materials from dominant rock in the area. Soils on steep slopes or rocky plateaus tend to be shallow. Soil located on the toeslope or concave draws has thick accumulation of hillslope material to develop a deep matrix for holding water. Valley bottoms, swales and fan slopes have accumulated sediments from adjacent slopes that increase porosity, mineral decomposition and may act as a deeper reservoir for soil water. Within the Malheur National Forest, the poorest growth soils are those with shallow depth (less than 20 inches) and developed on serpentine rock. Shallow soils have less volume to hold and transmit water while the serpentine outcrops have high contents of metal magnesium and nickel that inhibits plants.

The degree of soil development generally depends on the terrain created by the volcanic flowrock and intrusions. Headwaters consist of flow basalts and andesites of the Strawberry volcanics (Brown et al. 1966, Greene et al. 1972) to the north and welded tuffs and sedimentary rocks in the lower 2/3 of the MNF. Serpentine intrudes in scattered locations across the MNF with prominent exposures in the John Day and Middle fork John Day basins. During the Pleistocene, alluvial deposits consisting of tuffs, gravels and finer textured sediments accumulated in the valleys; these form the broad Bear Valley and Fox Basin, Murderer's Creek Basin and lower slope wash on the main stem John Day. The soils on the northern third of the MNF have volcanic ash deposits from Mt. Mazama.

Higher clays in the subsoil evolve where mass wasting occurs since the physical action decomposes minerals and serves as a conduit for slope water. Slump failures, most abundant along the north side of the Aldrich Mountains, form productive soils on flat benches, topographic troughs and depressions. These unstable areas provide higher fertility than the original bedrock derived soils.

The variable soil conditions are mapped at a fine scale for the northern portions of the Blue Mountain and Prairie City Districts, covering a third of the MNF area. This mapping provides soil property and productivity information used to predict risk for weed invasion and herbicide fate. The range of natural soils and more importantly the range of soil properties that could influence herbicide movement was derived by overlapping the Soil Survey Geographic Database (SSURGO) Database mapping with invasive plant sites. The mapping however, is complete only for the northern portion of the MNF and contains 41 percent of the invasive plant sites. The lack of soil mapping is not necessarily an impediment to analysis since the environmental fate of the herbicides is more related to the level of disturbance than the soil series, and the diversity of soils series within the mapped area is representative of the relevant soil properties across the MNF.

Table 2 lists the soil properties that contrast soil capacity to hold water and provide nutrients. Soil properties for organic matter, soil depth, hydrologic conductivity, cation exchange capacity and pH were derived from the NRCS Soil Data Viewer. Strong gradients in fertility are found between grassland and forest soils in the project area. Grassland and forb rich soils have high organic matter content along with finer textures that hold water longer into the dry season. The parent rock mineralogy affects the soil texture – degree of clay - rock content, cation exchange content, pH and available minerals. With exception to the valley bottoms, most of the MNF soils have high percent gravel to cobble rock fragments. The pH ranges from 6 to 7, having no indication of acidic or alkaline conditions that limit productivity.

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The cation exchange capacity (CEC) serves as an indicator for fertility and adsorption of applied herbicides. The cation exchange capacity is an index of available sites for solutes/ions to attach to soil particles. A higher CEC represents increased ability to hold and release various chemical elements – a relative higher capacity for holding nutrients. The soils in the project area have CEC of 5 to 35 meq/ gram of soil for mineral soil horizons (see Table 3). Humus, highly decomposed organic matter within the soil, has the strongest impact on overall CEC since humus itself has CEC in the range of 100 to 200 meq. The clay influenced soils have the highest CEC at 35 meq since clay minerals have high surface to volume ratios that bolster CEC. Though not listed in Table 3, grasslands with deep accumulations of organic matter will have CEC in the range of 30 to 50 CEC.

The dominant soil series in the northern half of the project area developed on andesite and basalt rocks and range from shallow to very deep soils. These series correlate with 23 percent of the invasive plant sites and comprise the Fivebeaver, Wonder, Bigcow and Rebarrow soil series. Soils derived in these volcanic ash materials generally have silt loam textures, gravelly to stoney conditions and clay contents less than 20 percent. These soils transmit water effectively at 70 to 97 µm/s except for the shallow Fivebeaver series. Higher water availability is found in the Wonder, Bigcow and Rebarrow soils which have higher ash deposition and deeper soil matrix. Available water in these ash influenced basalt and andesite soils has potential 9 to 14 cm; the range for all the mapped soils is 4 to 15 cm. Values below 4 cm indicate low available water.

Tuvame and Mellow soils, the dominant soils with valleys, account for 7 percent of the invasive plant sites. The poor to very poorly drained soils have seasonal water close to the surface, and support various sedge vegetation. These soils have very deep matrix and less rock than the volcanic soil on adjacent hillslopes. Available water in these soils depends on the closeness to the drainage; the loam to silt loam textures support moderate water movement through the soil profile due to lack clay to hold water. The available water is listed as only as 11 cm but the valley bottom position suggests water would be more abundant.

Soils that have inherently high erodibility include those on steep slopes, developed in volcanic tuff. Btree, Lamulita and Humarel soil series occur on tuff and welded pyroclasic flows, correlated to 6 percent of the invasive plant sites. The tuff decomposes easily forming clayey soils. Where deep and well developed the soil matrix has a high CEC at 35 meq, not including the MNF floor. Because of the finer texture, the water movement through the soil matrix is reduced compared to the andesite and basalt soils at 47 to 69 µm/s. These soils have values of available water similar to the harder rock volcanic soils at 7 to 14 cm, controlled mostly by soil depth.

The metavolcanic soils, which developed on very hard resistant rock, correlate with 4 percent of the invasive plant sites. These include the serpentine derived soils which have inherently poor growing conditions. The dominant soils series include the Lemoncreek and Hondu soil series which have ashy topsoil, and support mixed conifer forests. These rocky soils have less than 14 percent clay, siltloam to sandy loam textures and have low organic matter within the soil matrix. These soils have a low ability to hold water with only 7 cm estimated water.

Granitic derived soils only account for less than 1 percent of the invasive plant sites. Though normally well drained, the ash influence increases water holding capacity on these soils. The Gorhamgulch soil series is the predominant soil type. Soils support mixed conifer forest. The cation exchange capacity is moderate at 15 meq. Available water is high at 15 cm.

Table 2. Most common soil types from current soil mapping. Listed soils sort from dry to mesic vegetation type.

Soil series	Area (%)	Geology	Characteristic	Vegetation	Where found
Bocker	3.4	Andesite and Basalt	Shallow, mollisol	Sage steppe	Lava plateau
Anatone	2.2	Andesite and Basalt	Shallow, mollisol	Sage steppe	Lava plateau
Fivebeaver	5.0	Andesite and Basalt	Shallow, mollisol	Ponderosa pine and Douglas-fir	Plateaus and backslopes
Wonder	6.9	Andesite and Basalt	Ashy, rocky inceptisol	Mixed conifer forest	Montane ridges and shoulder slopes
Bigcow	6.2	Andesite and Basalt	Ashy, rocky inceptisol	Lodgepole pine and grand fir	Hillslopes
Bennett-creek	4.1	Andesite and Basalt	Thick ash, alfic forest soil	Ponderosa pine and Douglas-fir	Lower hillslopes and footslopes
Deardorf	2.2	Andesite and Basalt	Thick ash,rocky, moist forest soil	Mixed conifer forest	Montane ridges and shoulder slopes
Rebarrow	5.6	Andesite and Basalt	Thick ash,rocky, moist forest soil	Moist grand fir	Mountain valleys
Linecreek	2.2	Basalt	Ashy, rocky alfisol	Ponderosa pine and Douglas-fir	Plateaus, canyons, hills
Olot	2.0	Basalt	Thick ash, rocky forest soil	Mixed conifer forest	Mountains and plateaus
Tovame	4.0	Valley bottom	Somewhat poorly drained, terrace soils	Cinquefoil and sedges	Dry meadows
Melloe	3.2	Valley bottom	Poorly drained, aquic soils within valley alluvium	Alder and sedge	Wet meadows
Btree	2.9	Acidic Tuffs	Thick ash, alfic forest soil on tuff	Mixed conifer forest	Mountains and canyons
Lamulita	1.5	tuff breccia	Clay and rock, ashey, open forest soil on tuff	Grand fir, Douglas-fir, and ponderosa pine	Plateuas and hillslopes
Humarel	2.0	welded pyroclastic flows/ clay rich mafic	Clay and rock, ashey, open forest soil on tuff	Ponderosa pine and Douglas-fir	Hillslopes
Lemon-creek	2.3	Metavolcanics (serpentine)	Ashy, rocky forest soil on metavolcanics	Mixed conifer forest	Hillslopes
Hondu	1.4	argillite and metavolcanics	Deep and rocky, ashy dry forest soil on argillite and metavolcanics	Grand fir, Douglas-fir, and ponderosa pine	Hillslopes
Gorham-gulch	0.5	granite rock	Ashy, forest soil on granite	Mixed conifer forest	Hillslopes

*The percent area found within noxious weed mapping.

Table 3. Soil properties of prevalent soil series.

Soil series	Depth (in)	Dominant texture	Clay (%)	OM (%)	CEC*	Ksat**	Available water ***
Bocker	Shallow	cobbly siltloam	22.2	1.5	15	9	3.71
Anatone	Shallow	cobbly siltloam	23.2	1.82	21	9	2.61
Fivebeaver	Shallow	cobbly siltloam	18.4	6.34	21.4	23.56	4.51
Wonder	Very Deep	gravelly siltloam	6.2	16.45	15	97	9.56
Bigcow	Very Deep	gravelly siltloam	6.2	16.45	15	97	9.56
Bennettcreek	Mod Deep	siltloam	6.5	10.67	5	52.68	8.52
Deardorf	Very Deep	stoney siltloam	8.8	10.42	15	69.4	14.42
Rebarrow	Very Deep	siltloam	8.8	10.42	15	69.4	14.42
Linecreek	Mod Deep	extremely cobbly loam	6.5	10.67	5	52.68	10.06
Olot	Mod Deep	stoney siltloam	10.6	11.2	17	69.4	12.73
Tovame	Very Deep	siltloam	9	5.25	15	28	10.95
Melloe	Very Deep	loam	9	5.25	15	28	10.95
Btree	Deep	siltloam	8.8	11.42	15	69.4	14.86
Lamulita	Deep	clay loam	26.8	13.38	32.8	47.4	9.91
Humarel	Mod Deep	very gravelly clay loam	30.8	12.42	35.2	47.4	7.13
Lemoncreek	Mod Deep	siltloam	13.6	4.64	12.7	23.56	7.13
Hondu	Very Deep	sandy loam	6.6	4.78	14.7	25.08	7.14
Gorhamgulch	Very Deep	siltloam over cobbly sandy loam	6.2	11.42	15	52.68	15.08

*Cation exchange capacity in meq/100g for top 10 inches of soil
**Saturated hydrologic conductivity in top 20 inches soil (µm/s)
***Available water holding capacity within top 20 inches soil (cm)

Desired Condition

The Forest-Wide Standards for soil, riparian areas and water resources (USDA 1990) form the basis for the desired condition:

Soils: Maintain levels of soil productivity such that detrimental conditions shall not exceed 20% of the total acres of an activity area, including landings and roads. Consider restoration treatments if detrimental conditions are present on 20% or more of the activity areas. Detrimental soil conditions include compaction, puddling, displacement, and severely burned soil, and surface erosion (USDA 1990, p. IV-40).

Soils: Maintain minimum percent effective ground cover levels according to erosion class and year recovery (USDA 1990, p. IV-40).

Soils: Seed all disturbed soil that occurs within 100-200 feet of a stream or areas further than 200 feet that could erode into a stream.

Project Design Features

PDF Reference	Design Features	Purpose of PDF	Source of PDF
F - Herbicide Applications			
F3	Broadcast herbicide applications would occur when wind velocity is between two and eight miles per hour to reduce the chance of drift. During application, weather conditions would be monitored periodically by trained personnel.	To ensure proper application of herbicide and reduce drift.	These restrictions are typical so that herbicide use is avoided during inversions or windy conditions.
F5	No use of sulfonylurea herbicides (chlorsulfuron, sulometuron methyl and metsulfuron methyl) on dust laden bare soils. Avoid bare areas, >100 sq. ft., with powdery, ashy dry soil, or light sandy soil.	To avoid potential for herbicide drift.	Label advisory
H - Soils, Water and Aquatic Ecosystems			
H1	Follow herbicide use buffers shown below. Tank mixtures would apply the largest buffer as indicated for any of the herbicides in the mixture.	To reduce likelihood that herbicides would enter surface waters in concentrations of concern.	* Treatments within RHCAs are allowed if they meet Riparian Management Objectives (RMOs) therefore, herbicide use buffers are based on label advisories, SERA risk assessments and Berg's 2004 study of broadcast drift and run off to streams. Herbicide use buffers are intended to demonstrate compliance with R6 2005 ROD Standards 19 and 20.
H2	In riparian and aquatic settings, vehicles (including all-terrain vehicles) used to access invasive plant sites, apply foam, or for broadcast spraying will not travel off roadways, trails and parking areas if damage to riparian vegetation, soil and water quality, and aquatic habitat is likely.	To protect riparian and aquatic habitats.	Common protection measure
H3	Avoid using picloram and/or metsulfuron methyl on bare or	To preserve site recovery after disturbance, lessen	Label advisory

PDF Reference	Design Features	Purpose of PDF	Source of PDF
	compact soils, and inherently poor productivity soils that are highly disturbed. Poor soils include shallow soils less than 20 inch depth that lack topsoil and serpentine soils.	offsite runoff and leaching. Poor soils will have longer residence times with these persistent herbicides.	
H4	Do not use more than one application of picloram or metsulfuron methyl on a given area in a calendar year, except to treat areas missed during the initial application.	Reduce potential for accumulation in soil.	SERA Risk Assessments. Based on quantitative estimate of risk from worst-case scenario.
H5	Limit herbicide offsite transport on sites with high runoff potential including sites with: shallow seasonal water tables, saturated soils (wet muck and peat soils), steep erosive slopes with shallow soils and rock outcrop, or bare compacted and disturbed soils. Limit runoff by applying herbicide during the dry season with the lowest soil moisture conditions, where > 50% groundcover exists on shallow slope sites, and > 70% on steep slope sites, and/or at reduced rates.	Reduce potential offsite runoff transport of herbicides.	SERA Risk Assessments and Label. Based on quantitative risk for erosion and runoff.
H6	For soils with seasonally high water tables, do not use picloram or triclopyr BEE and limit glyphosate use to aquatic label only.	Reduce the risk for contamination of groundwater and offsite runoff to aquatic habitat and fish.	Label advisory
H7	Lakes and Ponds – No more than half the perimeter or 50 percent of the vegetative cover within established buffers or 10 contiguous acres around a lake or pond would be treated with herbicides in any 30-day period. This limits area treated within riparian areas to keep refugia habitat for reptiles and amphibians.	To reduce exposure to herbicides by providing some untreated areas for some organisms to use.	SERA Risk Assessments. Based on quantitative estimate of risk from worst-case scenario and uncertainty regarding effects to reptiles and amphibians.
H8	Wetlands – Wetlands would be treated when soils are driest. If herbicide treatment is necessary when soils are wet, use aquatic labeled herbicides. Favor hand/selective treatment methods where effective and practical. No more than 10 contiguous acres or fifty percent individual wetland areas would be treated in any 30-day period.	To reduce exposure to herbicides by providing some untreated areas for some organisms to use.	SERA Risk Assessments. Based on quantitative estimate of risk from worst-case scenario, uncertainty in effects to some organisms, and label advisories.
H9	Herbicide use would not occur within 100 feet of wells or 200 feet of spring developments. For stock tanks located outside of riparian areas, use wicking, wiping or spot treatments within 100 feet of the watering source.	Safe drinking water. To reduce the potential for herbicide delivery to watering systems used for grazing animals.	Label advisories and state drinking water regulations.

PDF Reference	Design Features	Purpose of PDF	Source of PDF
H10	Use of Triclopyr BEE is not allowed except in dry upland applications, not hydrologically connected to streams or ponds with water present.	Reduce the risk for contamination of groundwater and offsite runoff to aquatic habitat and fish.	Label and quantitative assessment for risk to aquatic organisms.
H11	Do not spray when local weather forecast calls for a ≥ 50% chance of rain.	Reduce potential offsite runoff transport of herbicides.	SERA Risk Assessments and Label. Based on quantitative risk for erosion and runoff.

Environmental Consequences

The Malheur Invasive Plants Treatment Project analyzes four alternatives: The No Action (Alternative A), the proposed action (Alternative B), an alternative with strict limits on herbicide use (Alternative C), and the action alternative without aminopyralid (Alternative D). See EIS, Chapter 2 in the EIS for a complete description of the alternatives.

The action alternatives treat invasive plants using manual, mechanical, biological agents, cultural methods and listed herbicides from the R6 2005 FEIS (USDA 2005). Alternative C caps treatment to 1,654 acres annually, eliminates broadcast spraying, restricts herbicide treatment within 100 feet of waterbodies and wetlands, and excludes use of picloram. Alternative D excludes the use of aminopyralid, but retains the same 2,124 acre per annum treatment.

Treatment of invasive plants target class A and B noxious weeds and most locations would likely concentrate along roadsides and facilities. On the MNF, invasive plants primarily grow in disturbed areas, particularly along roadsides outside of the forest canopy.

The general treatment area consists of 3,070 sites that cover 2,124 acres. Roughly ninety percent of the sites have infestations less than 1 acre. The current weed site mapping would serve as a baseline cap so treatment does not exceed 2,124 acres per year. Spatially, herbicide treatment would be limited to less than 10 percent within a six code watershed which ranges from 938 acres within the West Fork Burnt River watershed to 3803 acres within the Upper Little Malheur River watershed. Herbicides would be sprayed using backpack sprayers, brush, hose or booms. Both Alternatives B and D propose broadcast spraying. Aerial spraying is not proposed for any alternative.

Methodology

The R6 2005 FEIS analyzed herbicide effects to soil organisms and this analysis is incorporated by reference.

The main consideration for soils is the ability to filter and degrade herbicide residue depending on surface conditions. Site-specific soil and climactic conditions were modeled to examine the depth of percolation of herbicides for typical soil conditions.

Factors other than taxonomic soil type usually determine the fate of herbicides within the soil, such as of groundcover, compaction, gradient, and biological capacity. Biological capacity is the ability of soil organisms to decompose litter and relates directly to fertility. Higher amounts of organic matter, water, light and favorable temperature affects the ability of soil organisms to process vegetation and herbicide residue.

Soils were characterized using the Terrestrial Ecosystem Unit Inventory (TEUI) that is currently completed for a third of the Malheur NF. Older soils information (Carlson 1974) was used to analyze areas not yet covered by the TEUI.

The Groundwater Loading Effect of Agricultural Management Systems (GLEAMS) groundwater model was used to approximate risk for transport through soil, leaching, and runoff using site physical characteristics, local weather data and soil texture input (Available [ONLINE] @ http://www.tifton.uga.edu/sewrl/Gleams/gleams_y2k_update.htm). The model has parameters for climate, soils, topography, vegetation cover and size and flow rate of natural water bodies and application rate of herbicides. An extension, the GLEAMS-Driver module, allows use of local climate data. Weather records were used from CLIGEN, an extension available through the USDA Forest Service Water Erosion Prediction Project.

The GLEAMS model has parameters that require knowledge of runoff. These parameters were estimated using simulations from the Water Erosion Prediction Project's Disturbed WEPP model (USDA 2013). Groundcover and slope are two of the most sensitive drivers for runoff in this model.

Spatial and Temporal Context for Effects Analysis

Project duration is 5 to 15 years. Repeated treatments, manual, mechanical or chemical may be necessary in sequential years or the same year on the same ground (generally to treat missed plants during initial treatment). All action alternatives may result in repeated treatments through the life of the project. Active restoration may occur to reduce the time necessary after treatment to mitigate the effects of soil disturbance or persistence of various chemical herbicides.

Past, Present, and Foreseeable Activities Relevant to Cumulative Effects Analysis

Invasive plants respond to soil disturbance and spread from vectors. Past and ongoing forest activities that produce the highest rate of disturbance are those related to constructed surfaces such as administrative sites, road bases and extraction areas that include mines and rock pits. Past wildfire has high potential for spreading weeds. Timber and grazing has high potential for introducing invasive plants along travel routes where roads disturb and change the soil surface and traffic brings in seed source.

Alternative A – No Action

Direct and indirect effects

Alternative A would not authorize invasive plant treatments and thus would not have direct effects on the soil resource. Based on current spread rates (4-12% as per R6 2005 FEIS and ROD), invasive plant populations would continue to grow along the main travel corridors leading to higher risk for spread onto the Malheur National Forest. The effect on soils from invasive plant spread is a shift away from native plant and soil communities as invasive plants occupy new sites. Where invasive plants invade newly disturbed sites such as wildland fire areas, the invasive plants can affect the recovery trajectory for desired plant and soil communities.

Effects Common to All Action Alternatives

Direct and Indirect Effects from Non-herbicide Treatments

The non-herbicide treatments would have very minor effects on soils. Soil disturbance could occur from pulling invasive plants. Typical treatments result in less than 1 square foot loosened soil as pulling is typically used on sparse scattered infestations rather than large, densely infested areas. These disturbances do not adversely affect overall site productive capacity since they are small and distributed, and do not lead to substantial soil loss. The retained cover of non-target plant species curtails erosion of loosened soil. Bare soils would remain below 10 percent areal extent for a treatment site and restoration (mulching, seeding, planting) would occur as needed (see Chapter 2).

Direct and Indirect Effects of Herbicide Treatments

Herbicides would be sprayed directly on target species using ground based methods (hand, spot and broadcast) in all action alternatives; as per the PDFs, all methods, including broadcast would be implemented in a manner that reduces potential for non-target species and bare soil to be affected. Some soil will be directly sprayed by broadcast applications.

Herbicide application temporarily disturbs soils by altering vegetation cover and reducing the annual plant production. The effect is temporary, less than ten years, as desired vegetation returns. The disturbance does not result in detrimental soil disturbance that is an indication for permanent reductions to soil productivity.

The primary consideration for soils is the ability to filter and degrade herbicide residue depending on surface conditions. The major pathway for herbicide degradation is metabolism by soil microbes. Half-lives for herbicides range widely depending on the growing conditions for soil microbes. Herbicide decays from toxic levels by microbial decomposition, sunlight degradation, and hydrolysis after absorption in the soil profile (Bollag and Liu 1990). Most of the recommended herbicides primarily degrade by microbes metabolizing the residue (SERA 2004b,d,e, 2007, 2011a-d). Chlorsulfuron and metsulfuron methyl also degrade strongly by hydrolysis (SERA 2004a, 2004c).

Indirect effects of herbicide transport to non-target plants and to groundwater resources are influenced by soil properties. Herbicide labels list soil texture as one means to control offsite spread. Herbicide labels have broad applications with agricultural settings having bare soil as a prominent use. For the typical application on MNF, plant cover, groundcover, slope steepness and condition of the soil surface factor into the offsite movement in the MNF setting. Also, the degree of saturation and compaction contributes to runoff. Leaching corresponds to the position in the valley bottom, porosity of soil material, and rainfall that could transport herbicide residue downward along a wetting front. To the extent that organic matter and productive soils exist, leaching would largely be controlled for in the topsoil as soil microbes metabolize herbicide residue.

Direct and Indirect Effects to Soil Organisms

Impacts to soil organisms would be low and transitory due to the type of herbicide, low application rate, and MNF climate. The R6 2005 ROD (amended MNF LRMP) limited the use of herbicides to those that are unlikely to affect soil productivity and soil organisms. This analysis incorporates by reference the R6 2005 FEIS analysis and findings regarding impacts on soil organisms and productivity.

Impacts to soils and soil microbial community would largely be indirect, related to removal of targeted vegetation and shift to desired plant species. Changes in vegetation type can shift below ground composition of soil organisms (Wardle et al. 2004, Wolf and Klironomos 2005). Indirect boosts in decomposition rates may result as soil microbes metabolize dead plant tissue. Slight increases in microbial activity may occur as the bacteria break down the herbicide. This effect was observed by Ratcliff et al. (2006) where a growth increase in bacteria followed a glyphosate spill; the researchers reasoned that the increase is temporary as the bacteria metabolize the herbicide.

Eight of the ten herbicides approved in the R6 2005 ROD were not found to pose deleterious effects to soils. Picloram and sulfometuron methyl had potential affects to soil microbes in laboratory tests but not in field studies. These risks were reduced by limiting frequency and rate of application. The project proposes use of sulfometuron methyl at rates half that analyzed in the SERA risk assessment. Picloram use in Alternatives B and D have specific design criteria to avoid use on inherently poor soils and limit repeat application (PDF H3 and H4). Picloram would not be used in Alternative C.

Aminopyralid may be used in Alternatives B and C. The 2007 SERA Risk Assessment does not indicate any risk to soil microbes.

Using non-site specific circumstances, the SERA risk assessments indicated potential short term impacts to soil organisms for picloram, imazapyr, metsulfuron methyl, and sulfometuron methyl. In laboratory assays, short term decreases for some types of soil microbes are reported with high concentrations above the amounts modeled for the MNF soils. The herbicides effects decrease with time as other microbes, less sensitive to herbicide, decompose the active ingredient. Table 4 contasts the microbial decomposition of each herbicide using half life. Persistent herbicides such as picloram have longer half-lives. Impacts to microbes would be least where soils have a high degree of productive capacity with adequate organic matter, aeration and moisture.

For picloram, the SERA risk assessment cited a slight decrease in the N fixing bacteria Azotobactor for a two week period at picloram concentrations of 10 ppm (see Tu 1994). In general, laboratory assays found little detectible changes in microbial activity below 50 ppm soil concentrations (SERA 2011c). Within the SERA risk assessment, GLEAMS model results show that for the clay, loam and sandy soils the soil concentration after application would be below 10 ppm. Results for GLEAMS-Driver modeling on the MNF sites for a typical silt loam soil would have 0.3 ppm of picloram following treatment (figure 4). The GLEAMS-Driver is a module that uses climate data specific to an area. Given picloram' s persistence (half-live 80 days to 3 years), this project limits application to once for year (PDF H4). Similarly, picloram is excluded from use on poor soils where natural plant communities are desired (PDF H3). The emphasis on natural plant community addresses uses on administrative sites and roadsides which have unique conditions that favor desired non-native species as protective groundcover.

For metsulfuron methyl, findings from one study showed slight growth reduction of common soil bacterium above 5 ppm soil concentrations (SERA 2004c). These effects increased with dosage. Modeled metsulfuron soil concentrations are 0.06 ppm. As with picloram, metsulfuron methyl is known to be persistent with half-live of 120 days (see Hydrology section). In agricultural studies, metsulfuron methyl use was linked to damaged rotation or substitution crops from persistence (Yu et al. 2005). The Yu et al. (2005) study demonstrated the detoxifying efficacy of a certain fungus that used metsulfuron methyl as a carbon source. Given the persistence and reliance of microbial degradation, the proposed action is for half the use rate commonly used in USFS applications (see SERA analysis 2004c). The project limits potential buildup of this persistent herbicide by limiting to once per season and avoiding use on poor soils where decomposition rates are low and native vegetation is desired (PDF H3, H4).

Tests for sulfometuron methyl depressing microbial activity showed mixed results from laboratory studies (SERA 2004d). Studies found both no effect and lower microbial biomass using herbicide concentrations near the rates evaluated in the SERA risk assessment. Overall, the risk assessment information was uncertain on the effects to any particular microbial group. Since herbicide half-life indicates the decomposition and thus microbial activity, this provides some indication on the toxicity. Field studies suggest the half-life is at 10 to 100 days (SERA 2004d) with higher decomposition in humid climates (Anderson and Dulka 1985). The half-life range shows ready decomposition by at least some microbial groups.

The proposed application rates for sulfometuron methyl are half of the rate used by the SERA risk assessment and modeled soil concentrations less than half that used in the environment fate experiment by Anderson and Dulka (1985). Note, this study showed that soil concentrations of 0.14 ppm followed first order decay equations, suggesting that no depression of microbial activity was found. The proposed level of sulfometuron methyl would have soil concentrations at 0.11 ppm, slightly lower than that used in the study.

The direct effect of herbicides on fungal and bacterial soil microorganisms vary with the herbicide used, and even then depend on the residue reaching the soil and the degradation rate, or half-life of the chemical. The effect to micro-organisms is usually not gauged by direct measurements, but inferred by changes in productivity factors such as respiration (CO2 production), of which microbial activity is one cause (SERA, 2011b). However the measurement of toxicity of herbicides to soil micro-organisms may be relevant only in the soil medium itself. Busse et al. (2001) showed that glyphosate, which can be toxic to microbes grown directly on the herbicide in the laboratory, had an un-measurable effect on microbes when applied directly to soil in the laboratory or in the field. In a follow-up study on glyphosate effects to soil microbial community structure, Ratcliff et al. (2006) showed a sizable increase in the bacteria to fungal ratio for the spill scenario (100% solution) and not for the diluted field rate. The increase may be only temporary as bacteria metabolize the herbicide, a labile carbon source, with an anticipated return to normal composition as the active carbon supply returns to natural levels.

Imazapyr and triclopyr have been shown to temporarily depress microbial activity for select organisms. Imazapyr soil concentrations over 20 ppm were reported to slow cellulose decomposition by microbes in the lab (SERA 2011d). For the Malheur National Forest project, predicted soil concentrations are 0.50 ppm, below the 20 ppm level that effects were found. Triclopyr has reportedly significantly slowed growth of bacterial and fungal strains in laboratory assays where over concentrations exceeded 1000 ppm (SERA 2011a). Some fungal strains had detectible changes to growth down to as little as 0.1 ppm. When testing natural soil samples, no detectible changes to microbial function or community structure was found for a rate of 1.2 lb. a.i./acre (Houston et al. 1998). The typical rate for triclopyr on the Malheur National Forest would be 1 lb./acre. Model runs using a high rate at 2 lb./acre show average soil concentrations of 0.6 ppm. At this concentration, triclopyr has very low potential for slowing fungal growth.

Table 4. Compiled herbicide properties for mobility in soil and water transport from SERA risk assessments.

Herbicide	Toxicity to Soil Microbes*	Adsorption	Water Solubility (mg/l)	Degradation Half-Life (days)		
				Soil Microbes	Water and Sunlight	Ground-water
Aminopyralid	low	low	205,000 pH 7	14-343	0.6	127-447
Clopyralid	Low	low	1,000	12-70	8-40	261
Chlorsulfuron	Low	low; very low in clay soils	27,900 pH 7	120-180	?	37-168
Glyphosate	Low	strong	12,000	3-130	4-11	50-70
Imazapic	no info	moderate	>2,670 mg/l	25-142	1-2	30
Imazapyr	Slight	low	13,100	313	2-20	325
Metsulfuron Methyl	moderate for high application rates on poor soils	very low	2,790	120	1	1213
Picloram	moderate for high application rates on poor soils	very low	200,000	80 to 3 years	3-14	none
Sulfometuron Methyl	Low	low	300	10-100	1-14	113
Triclopyr TEA (salt)	Low	low	8,100 mg/l	14-46	2-6 **hours**	6 **hours**
Triclopyr BEE (ester)	Low	moderate	7.4 mg/l	40	0.5-9	No data

*Reported temporary depressed effects to some microbial groups for imazapyr, metsulfuron methyl, picloram, sulfometuron methyl, and triclopyr. Categorical risk is assigned based on proposed use rate compared to laboratory studies outlined in the SERA risk assessments.

Qualitative discussion on harm to soils

The capacity for soil microbes to decompose herbicide residue would be greater on natural soils compared to developed environments such as roads, and facility pads. The herbicides have wide-ranging half-lives depending on the biological capacity in the soil. The SERA risk assessment for aminopyralid lists half- lives of 14-343 days (SERA 2007). Since the microbial decay of herbicide is the primary fate, high productivity soils decrease the half- life and thus residency.

Decomposition processes need adequate water supply, air and carbon, which is highest on natural surfaces. Water has been shown the most critical factor for productivity, as microbial activity drops substantially under soil moisture content of ten percent (Davidson et al. 1998). Litter and forest floor layers provide a large proportion of CEC capacity that adsorbs herbicide residue. The litter and forest floor also reduces water losses to evaporation.

Eighty three percent of the currently mapped infested acres occur along roadsides and administrative sites that are non-natural sites. Since these constructed surfaces lack diverse plants and soil microbes, herbicide decay by soil microbes would be reduced. However, herbicides would also decay by photolysis for all selected herbicides. Similar effects would apply to compacted and bared soils such as skidtrails, log landings, off-road parking, and cattle troughs.

Inherently poor soils include shallow, droughty and serpentine soils. These soils have less capacity for decomposition and thus result in longer herbicide residence times. Thin basalt soils are prevalent across the MNF, but have high concentrations of organic matter in the topsoil that alleviates concern. Serpentine soils have isolated locations across the forest. The highest density is within in the northern portion of forest which coincides with the fine scale SSURGO mapping. Of the invasive plant sites, twenty sites occur on road templates on or adjacent to serpentine soils comprising 62 acres. Mapped as either Lemoncreek or Cotay soil series, these soils have ash influence that would ameliorate the poor growing conditions associated with serpentine. The Lemoncreek soil has shallow topsoil and thus a higher risk than the Cotay soil series. The infestations have primarily Canada thistle and sulphur cinquefoil. The sites situate in the Mosquito Creek-upper Bear watershed that drains to the Middle Fork John Day River. Most occur within the old Summit Wildfire burn area. Other sites include Little Boulder Creek-Deerhorn and Vinegar Creek subwatersheds of the Middle Fork John Day River.

Where shallow and disturbed soils exist and the desired condition is to restore natural vegetation rather than maintaining vegetation cover and excluding invasive plants, the use of picloram and sulfometuron methyl could reduce potential revegetation. These herbicides persist and poor soil conditions could lengthen already long residency times. The climatic limits, PDFs and herbicide use buffers minimize the potential for leaching and runoff thereby reducing risk to the extent possible. Picloram application is limited to once per year and excluded on poor soils, or shallow soils where productivity may be reduced to the extent that decomposition of the herbicide residue would be stalled (PDFs H3, H4). This effectively reduces the potential for picloram to build up in the soil and have impacts on soil organisms or productivity.

Environmental fate

Herbicide decays from toxic levels by microbial decomposition, sunlight degradation, and hydroloysis after absorption in the soil profile (Bollag and Liu 1990). Most of the recommended herbicides primarily degrade by microbes metabolizing the residue (SERA 2004b,d,e, 2007, 2011a-d). Chlorsulfuron and metsulfuron methyl also degrade strongly by hydrolysis (SERA 2004a, 2004c).

Overall, risk for runoff and leaching is low since treatments generally occur during the dry season. Roughly 19% of annual precipitation occurs during this time. Since much of the runoff can occur with storms, herbicide application is avoided if the forecast is for rain (H11) and limited to the dry season (PDF H5). A study by the USFS on road shoulder runoff found that risk for runoff decreased 1.5 times from the first day to the second week after spraying (Wood 2001). The marked decrease is from the herbicide adsorbing to vegetation and soils.

The highest runoff potential occurs on compact surfaces at forest administration sites and along roads. Sloped areas with thin soils and bedrock near the surface force lateral soil throughflow and can induce runoff. Cutslopes along roads with rock faces and rocky thin soils on hillslopes have high potential runoff. Outside of these disturbed or steep thin soil sites, most natural forested areas have well drained soils consisting of silt loam texures and high rock contents in excess of 35% that facilitate rapid drainage.

Saturated conditions also promote runoff found along valley bottoms and swales, most prominent following spring precipitation. Application in late spring could have higher risk for encountering saturated conditions after spring snowmelt. PDF H5 limits application to avoid the runoff risk from saturated soils.

Leaching is associated with areas that experience a wetting front that can transport herbicide residue below ground. Valley bottom and alluvial fan areas that accumulate water from adjoining hillslopes have the highest potential for leaching. Heavy rainfall following spring would have a higher likelihood of transporting contaminants downward since moist antecedent conditions would facilitate percolation. Successive rainfall events that transport contaminants downward are rarer during the main period of treatment, June through September. The risk for downward percolation is highest for herbicides that have a higher residency time are stable in water. Picloram and metsulfuron methyl have very slow decay rates once they move below the biologically active soil layer (see Table 4). An additional mitigation is used to limit application to once per year to limit risk for accumulating these herbicides in groundwater (see PDF H4).

To consider risk for offsite transport on a site by site basis, the planned treatment sites were evaluated using highest herbicide application rates as a worst case scenario. Fish, aquatic plants and water quality indicators were used to evaluate the risk for offsite transport at four sites from the project area (see Hydrology report). The sites represent a range of soil conditions with four having high importance from their adjacency to Bull trout streams. Soil properties at each site were identified for use in the groundwater effects model (GLEAMS-Driver) to examine the fate of herbicides in the rooting zone and offsite along the soil surface. The GLEAMS model is the same model used for the SERA risk assessments. Though an agriculture model, several important soil condition parameters incorporate site condition such as compaction, groundcover and topography. Output is approximate for the herbicides.

The GLEAMS model was used to examine the fate of herbicides in the rooting zone of the soil and to evaluate the potential for herbicides to run off or leach through soils and reach water bodies. The modeling included a scenario for herbicide application on the most common soil type along a roadside. Figure 4 displays the results by soil depth versus magnitude of herbicide concentration. Dot size represents the level of herbicide concentration (larger dots mean more herbicide found in that soil layer). The Wonder soil series was used, having gravelly silt loam topsoil over gravelly loam subsoil and developed in andesite and basalt parent material to greater than 80 inch depth. Climate data was taken from the nearby Austin station and modeled for summer.

The results of the GLEAMS modeling shows all the herbicides do not penetrate lower than 36 inches using the highest application rates. The faint dot of aminopyralid represents small herbicide concentrations. The sharp decrease in depth illustrates the adsoption of herbicides to soil despite their high solubility. The topsoil organics and mineral matrix bind the bulk of the herbicide in the top inches as reflected in the modeling results.

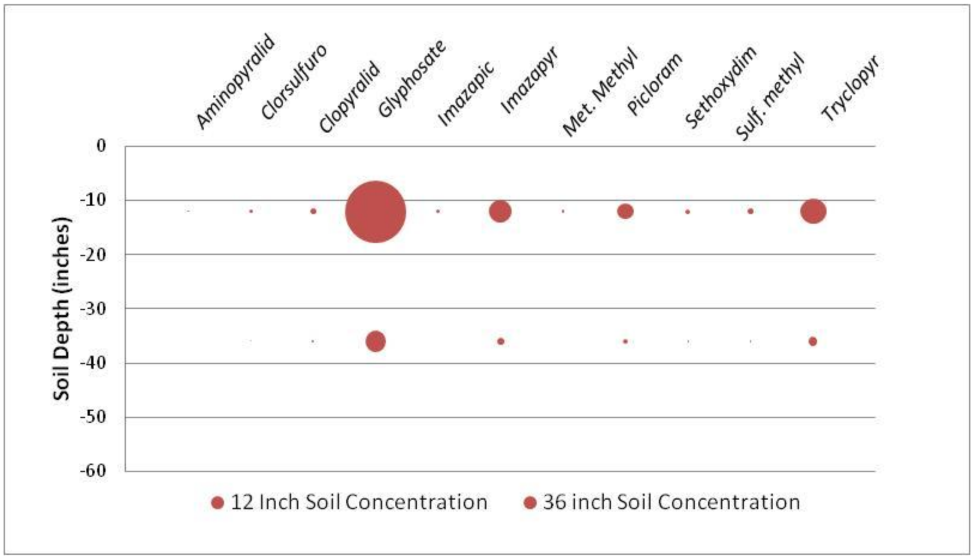

Figure 4. Modeled soil concentrations (ppm) on Wonder Series soils in the Clear Creek watershed

Despite the low risk for offsite transport by water, a risk for offsite transport by dust was identified for the sulfonylurea herbicides where applied to bare soil conditions along roadsides, native surface roads and cleared vegetation areas. Chlorsulfuron, sulfometuron methyl, and metsulfuron methyl binds particularly tightly to clay particles. Risk to non-target plants from herbicide-laden dust was addressed in the risk assessments for these herbicides. To mitigate this risk, these herbicides can only be applied on ashy soil, or light sandy soil during moist conditions (PDF F5). Further, application during calm wind conditions lowers risk for offsite transport (PDF F3).

Early Detection Rapid Response

The current invasive plants sites represent the range of environmental conditions expected on the MNF thereby accounting for potential consequences. These conditions were used to analyze and produce project design features that establish a sufficient layer of protection for soil organisms and to limit offsite transport to non-target plants and groundwater.

Manual, mechanical and cultural treatments result in very small disturbances, less than 1 square foot, which would not be large enough to have adverse cumulative effects when combined with past and ongoing MNF activities.

Repeated treatment of herbicides was raised as a concern. The low toxicity and low application rates reduce this risk overall; note that the typical rate would be used in most cases. The eleven herbicides used under this alternative have relatively short half-lives, at less than 3 months where productive soils (table 4). Buildup from repeated uses of picloram and metsulfuron methyl was identified as a concern based on findings from the SERA assessments (SERA 2004d, 2011c). Using these herbicides would have short term transient effects that could slow growth of select soil microbes. These herbicides have half-lives of 90 days and 10-100 days (table 4) depending on soil conditions. The project limits use of metsulfuron methyl to once a year to minimize soil buildup (PDF H4). Since soil conditions determine the buildup potential – a lack of soil microbes equates to lack of decomposition – the use of metsulfuron methyl and picloram would be avoided where wanted to restore vegetation on sites with poor soil conditions (PDF H3). Gravel pits and parking lots would be examples of infertile areas where herbicide buildup would not be a concern.

Cumulative Effects Common to All Action Alternatives

Treatment scenarios would not measurably affect soils or soil productivity when compared with background conditions and ground disturbance created by ongoing activities. Thus, there is no potential for these effects to cause additive, synergistic, or other negative long term cumulative effects. Manual, mechanical and cultural treatments would likely result in very small disturbances, less than 1 square foot, which would not be large enough to have adverse cumulative effects when combined with past and ongoing MNF activities.

Most forest or riparian sites proposed for treatment will have treatment and monitoring of invasive populations extended through the project term (15 years). Foreseeable management activities on these sites are dispersed recreation travel, prescribed burns, wildfire suppression activities, and vegetation management including timber harvest. Although these activities could result in direct detrimental disturbance to the sites, the effects to soils from herbicide applications proposed under this project are unlikely to incrementally change soil characteristics enough to alter the productivity of any treated sites. Activities proposed under this project are not likely to be additive to the impacts of any other activities that could be cumulative to existing conditions on these sites.

The ongoing forest management and recreation activities in addition to natural disturbance from wildfire create the potential for increased use of herbicide and/ or manual treatments. The proposed herbicide spraying assumes a reduction in treatment over time. However, ongoing forest activities may increase the open sites available for invasive plants to spread. The risk is controlled by existing prevention measures. Timber sale contracts have provisions to wash rigs as do fire suppression activities. Similarly, road management has specific contractual agreements that control against invasive plant spread.

Reasonably foreseeable actions

The effects of the herbicide treatments do not harm soil organisms but do change the vegetation composition which results in a minor level of disturbance. Ongoing management activities outlined in the EIS create a very large disturbance footprint compared to the effects of any action alternative. A list of forestwide projects are scheduled (2013-2015) that will be concurrent with the action alternatives (see EIS Chapter 3). These projects include: prescribed burning, plantation thinning, replacing road culverts, road decommissioning, snow park relocation, aspen release, juniper thinning, toilet replacement, commercial timber harvest, parking lot paving, gate replacement, and demolition of a structure by explosion, fencing and other sundry and related activities. Most of the activities will involve a level of ground disturbance and many will probably risk increasing sediment delivery to streams.

Figure 5 shows the median disturbance acreage for the MNF for the past ten years. The data was extracted from the forest FACTS layer; roads have buffers, 60 to 100 ft width, corresponding to maintenance level and fences have a 10 foot buffer. The median values for prescribed fire, timber harvest and wildfire are given for the past ten years. High severity disturbance results in detrimental soil conditions that reduce native vegetation cover and impairs soil function. Detrimental disturbance results when management activities physically alter soils and remove organic matter to the extent that soil recovery remains very slow (USDA 1998). Low severity disturbance results in short term reductions to vegetation cover that last less than ten years. Invasive plant treatment would not be considered a high severity disturbance. Invasive plant treatment might temporarily slow recovery of native vegetation within some treatment sites, but would eventually help restore desired vegetation.

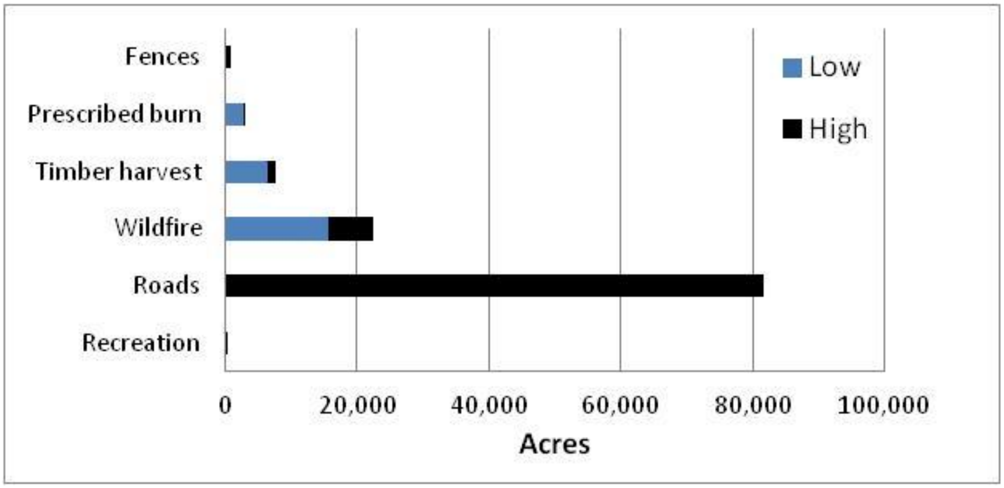

Figure 5. Disturbance from other forest activities.

Road related disturbance accounts for the most extensive disturbance across the forest. Most of the existing invasive plants are mapped along road templates (83 percent). The road templates are not intended as a part of the productive land base and thus minor changes to plant cover from herbicide treatment would not have adverse effects.

Outside of the roads, herbicide application impacts vegetation cover on roughly 85 acres where maintaining a productive land base is the primary purpose. For this area, the MNF forest activities or disturbances result from livestock grazing, timber and fuel management, prescribed fire, and wildfire. Herbicide application within areas disturbed by recent MNF activities could temporarily slow the recovery trajectory of native vegetation. The impact would temporarily decrease soil productivity by decreasing overall plant production. Soil productivity would recover as desired vegetation re-establishes.

The short term reduction in vegetation growth that creates minor soil disturbance is a tradeoff. Given the large disturbance footprint and continued invasive plant presence along the roads, future additive effects from herbicide application and forest activities are reduced if treatment occurs along prominent vectors. The proposed methods reduce populations of invasive plants at rock pits and stockpiled road materials. Using invasive plant-free road materials (i.e. rock and gravel) cuts down the potential spread onto adjoining road prisms and within planned harvest units. Administrative sites, campgrounds, roads—essentially all areas that have unnatural surfaces and perpetual propagule pressure from traffic flow have the highest risk for cumulative increase in invasive plant spread. These activities correspond to 79 percent of the current invasive plant sites. Since other activities - whether range, timber, or recreation management - largely depend on road access, the extent of the infrastructure represents the net effect of all the MNF activities.

The action alternatives reduce the chance for spreading invasive plants from other forest management activities by controlling the level of infestation. The proposed methods reduce populations of noxious invasive plants at rock pits and stockpiled road materials. Insuring invasive plant free road materials cuts down the potential spread onto adjoining road prisms and within planned harvest units. Administrative sites, campgrounds, roads have unnatural surfaces and perpetual propagule pressure from traffic flow have the highest risk for cumulative increase in invasive plant spread. These activities correspond to 79 percent of the current noxious invasive plant sites.

Vegetation management, including timber harvest, may result in a heavy disturbance, although there would be rapid recovery of native vegetation. Currently, the MNF harvests roughly 7,583 acres of timber annually using the median value from the last 10 years. However, together with wildfire, only 6 percent of the invasive plant sites correlate with timber harvest and wildfire events.

Livestock grazing requires road access and creates heavy disturbance along fence lines, and around stock ponds and troughs. This disturbance has a small footprint; cattle trails typically have 2- to 4-foot width and stock troughs may have ¼-acre compacted barren ground. These features are evenly distributed across thousands of acres, as opposed to confined disturbance that results from timber harvest or wildfire. The distributed nature and seasonal disturbance creates a moderate risk for cumulative effects from livestock grazing. Two percent of the invasive plant sites can be attributed to grazing, while disturbance along fence lines forest-wide accounts for 0.3 percent of all known infested areas.

Differences between Alternatives

The differences between alternatives would not substantially change their impact on soils because manual and herbicide treatments of invasive plants on the Malheur NF are unlikely to affect soil properties or productivity. Properties of soils on the MNF limit off-site movement of herbicides through the soil profile. Alternative B utilizes the most aminopyralid and allows the most broadcasting of the alternatives. Alternative C reduces the amount of herbicide used, and excludes use on sites that fall within 100 feet of streams, lakes, ponds and wetlands. This alternative also excludes use of picloram. Thus, the risk for herbicide buildup is reduced in this alternative because so little herbicide is comparatively used and because picloram is eliminated.

Alternative D would use 440 more acres of chlorsulfuron, 725 more acres of glyphosate and 63 more acres of picloram as first choice herbicides. However, the PDFs, herbicide use buffers and project caps ensure there would be no measurable adverse effects to soil from these differences.

Compliance with the Malheur Land and Resource Management Plan (LRMP) and Other Relevant Laws, Regulations, Policies and Plans

Proposed treatments in all action alternatives would not lead to detrimental soil disturbance, nor substantially add to levels of detrimental disturbance from prior activities. Thus, the MNF LRMP plan standard to retain effective cover would be met. Further, most of the invasive plant treatments occur on administrative use lands where productivity is not the primary purpose. All alternatives would meet Malheur NF objectives (USDA 1990, p. 4-21) and regional guidance (USDA 1998) for soils.

Summary of Effects

All action alternatives expand the tools for controlling invasive plants. Non-herbicide treatments would have negligible effects to soils. Soils would also not be adversely affected from the herbicide treatments due to the typical rates of application and the prevalence of sites on non-natural surfaces such as road sides, trailways, and at parking areas. Soil productivity would not be directly affected. Indirect effects may include a shift in the composition of plant and soil biota related to use of herbicides. However the project design features applied to all action alternatives make this unlikely because restrictions on the rate, type, and frequency of specific herbicides (see PDF Groups F and H, Chapter 2 in the EIS) would reduce herbicide build up in the soil and impacts on soil organisms or productivity.

References

Anderson, J.J. and J.J. Dulka. 1985. Environmental fate of sulfometuron methyl in aerobic soils. J. Agric. Food Chem. 33: 596-602

Bashkin, M., T.J. Stohlgren, Y. Otsuki, m. Lee, P. Evangelista, and J. Belnap. 2003. Soil characteristics and plant exotic species invasions in the Grand Staircase-Escalante national Monument, Utah, USA. Applied Soil Ecology. 22(1): 67-77

Birdsall, J.L., W. McCaughey, and J.B. Runyon. 2011. Roads impact the distribution of noxious weeds more than restoration treatments in a lodgepole pine forest in Montana, U.S.A. Restoration Ecology: 1-7

Bollag, J.M., and S.Y. Liu. 1990. Biological Transformation Processes of Pesticides. In Pesticides in the Soil Environment. H.H. Cheng. (ed.) Soil Science Society of America book series, no. 2. Madison, Wis., USA: Soil Science Society of America. p. 169-211Booth et al 2006

Brown, C.E. and T.P. Thayer. 1966. The Geologic Map of the Canyon City Quadrangle, Oregon. USGS Miscellaneous Geologic Investigations Map I-447.

Buonopane, M., G. Snider, B.K. Kerns, and P.S. Doescher. 2013. Complex restoration challenges: weeds, seeds, and roads in a forested Wildland Urban Interface. Forest Ecology and Management. 295: 87-96

Busse, M.D., A.W. Ratcliff, C.J. Shestak, and R.F. Powers. 2001. Glyphosate toxicity and the effects of long-term vegetation control on soil microbial communities. Soil Biology & Biochemistry (33) 1777-1789.Callaway, R., G.C. Thelen, A. Rodriguez, and W.E. Holben. 2004. Soil biota and exotic plant invasion. Nature. 427: 431-433

Carlson, G. 1974. Malheur National Forest Soil Resource Inventory. Unpublished In-Service Report. USDA Forest Service, Pacific Northwest Region, Malheur National Forest. John Day, OR. 137p.

Daly, M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology. 34p.

D'Antonio, C.A. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Syst. 23: 63-87

Dassonville, N., S. Vanderhoeven, V. Vanparys, M. Hayez, W. Gruber, and P. Meerts. 2008. Impacts of alien invasive plants on soil nutrients are correlated with initial site conditions in NW Europe. Oecologia. 157(1) : 131-140

Davidson, E.A., E. Belk, and R.D. Boone. 1998. Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. Global Change Biology. 4: 217-227.

Dooley, S. and J. Beckstead. 2010. Characterizing the interaction between a fungal seed pathogen and a deleterious rhizobacterium for biological control of cheatgrass, Biological Control. 53: 197-203

Ehrenfeld, J.G., P. Kourtev, and W. Huang. 2001. Changes in soil functions following invasions of exotic understory plants in deciduous forests. Ecological Applications 11(5) 1287-1300.

Ehrenfield, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 6: 503-521

Eviner, VT, MK Firestone. 2007. Mechanisms determining patterns of nutrient dynamics. in M. stromberg, J. Corbin, and C D'Antonio (eds) Ecology and management of California grasslands. pp. 94-106

Flory, S.L., and K. Clay. 2009. Effects of roads and forest successional age on experimental plant invasions. Biological Conservation. 142: 2531-2537

Gelbard, J.L., and J. Belnap. 2003. Roads as conduits fore exotic plant invasions in a sermiarid landscape. Conservation Biology. 17(2): 420-432

Greene, R.C., G.W. Walker, and R.E. Corcoran. 1972. The Geologic Map of the Burns Quadrangle, Oregon. USGS Miscellaneous Geologic Investigations Map I-680.

Gundale, M.J., S. Sutherland, and T.H. DeLuca. 2008. Fire, native species, and soil resource interactions influence the spatio-temporal invasion pattern of *Bromus tectorum*. Ecography. 31: 201-210

Guo, D., P. Mou, R.H. Jones, and R.J. Mitchell. 2004. Spatio-temporal patterns of soil available nutreints following experimental disturbance in a pine forest. Oecologia. 138: 613-621

Hansen, M.J., and A.P. Clevenger. 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. Biological Conservation. 125: 249-259

Hart, S. C., T. H. DeLuca, G. S. Newman, M. D. MacKenzie, and S. Boyle. 2005. Post-fire vegetative dynamics as drivers of microbial community structure and function in forest soils. Forest Ecology Manual. 230: 166-184

Hawkes, C.V., I.F. Wren, D.J. Herman, and M.K. Firestone. 2005. Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. Ecology Letters. 8: 976-985

James, J.J., B.S. Smith. E.A. Vasquez, and R.L. Sheley. 2010. Principles for ecologically based invasive plant management. Invasive Plant Science and Management. 3: 229-239

Korb, J.E., N.C. Johnson, and W.W. Covington. 2004. Slash pile burning effects on soil biotic and chemical protperies and plant establishment: recommendations for amelioration. Restoration Ecology. 12(1): 52-62

Kulmatiski, A., K.H. Beard, J.R. Stevens, and S.M. Cobbold. 2008. Plant-soil feedbacks: a meta-analytical review. Ecology Letters. 11: 980-992

Houston, A.P.C., S. Visser, and R.A. Lautenschlager. Response of microbial processes and funal community structure to vegetation management in mixedwood forest soils. Canadian Journal of Botany. 76: 2002-2010

Lacey, R.C., C.B. Marlow and J.R. Lane. 1989. Influence of spotted knapweed (Centaurea maculosa) on surface runoff and sediment yield. Weed Technology (3) 627-631.

Lauenroth, W.K., D.G. Milchunas, J.L. Dodd, R.H. Hart, R.K. Heitschmidt, and L.R. Rittenhouse. 1994 . Effects of grazing on ecosystems of the Great Plains . Pages 69 - 100 in Vavra, M., W.A. Laycock, and R.D. Pieper Editor(s). Ecological implications of livestock herbivory in the West. Society for Range Management, Denver, CO.

Lejeune, K. and T. Seastedt (2001). "*Centaurea* Species: the Forb That Won the West." Conservation Biology 15(6): 1568-1574.

Lloyd, R.A., K.A. Lohse, and TPA Ferré. Influence of road reclamation techniques on forest ecosystem recovery. Front. Ecol. Environ. 11(2): 75-81

Meyer, N. 2009. Soil and Plant Response to Slash Pile Burning in a Ponderosa Pine Forest. M.S. Thesis, Department of Land Resources and Environmental Sciences. Montana State University, MT. 98pp.

Norton, J.B., T.A. Monaco, and U. Norton. Mediterranean annual grasses in western North America: kids in a candy store. Plant Soil. 1-5

Olson, B. E., 1999. Impacts of invasive plants on ecologic and economic systems. Pages 4-18 in Biology and Management of Noxious rangeland weeds. R. L. Sheley and J. K. Petroff (Eds.). Oregon State University Press, Corvallis.

Oregon Department Of Environmental Quality. 2010. Water Pollution. Division 41. Water Quality Standards: Beneficial Uses, Policies, and Criteria For Oregon. 340-041-0001 to 0350

Ortega, Y.K., D.E. Pearson. 2005. Weak vs. strong invaders of natural plant communities: assessing invisibility and impact. Ecological Applications. 15(2): 651-661

Ratcliff, A.W., M.D. Busse, and C.J. Shestak. 2006. Changes in microbial community structure following herbicide (Glyphosate) additions to forest soils. Applied Soil Ecology. 34: 114-124

Rinella, M.J., B.D. Maxwell, P.K. Fay, T. Weaver, and R.L. Sheley. 2009. Contorl effort exacerbates invasive-species problem. Ecological Applications. 19(1): 155-162

Seastedt, T.R., R.J. Hobbs, and K.N. Suding. 2008. Management of novel ecosystems: are novel approaches required? Front. Ecol. Environ. 6(10): 547-553

SERA. Nov. 21, 2004a. Chlorsulfuron—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc., 5100 Highbridge Street, Fayetteville, New York 13066-0950.

SERA. Dec. 5, 2004b. Clopyralid—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc., 5100 Highbridge Street, Fayetteville, New York 13066-0950.

SERA. Dec. 9, 2004c. Metsulfuron Methyl—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Dec. 14, 2004d. Sulfometuron Methyl—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Dec. 23, 2004e. Imazapic—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Jun. 28, 2007. Aminopyralid—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. May 24, 2011a. Triclopyr—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Mar. 25, 2011b. Glyphosate—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Sep. 29, 2011c. Picloram—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.

SERA. Dec. 16, 2011d. Imazapyr—Human health and ecological risk assessment—final report. Syracuse Environmental Research Associates, Inc. Fayetteville, New York 13066-0950.Steinlein 2013

Steinlein, T. 2013. Invasive alien plants and their effects on native microbial soil communities. Progress in Botany. 74: 293-319

Suding, K.N., K.D. LeJeune, T.R. Seastedt. 2004. Competitive impacts and responses of an invasive weed: dependencies on nitrogen and phosphorus availability. Oecologia. 141: 526-535

Sutherland, S. 2004. What makes a weed a weed: life history traits of native and exotic plants in the USA. Oecologia. 141: 24-39

Tu, C.M. 1994. Effects of herbicides and fumigants on microbial activities in soil. Bulletin of Environmental Contamination and Toxicology. 52(1): 12-17

USDA Forest Service. 1988. Malheur NF Invasive Plant Project. In-Service Report. USDA Forest Service, Region 6, Malheur NF. John Day, OR.

USDA Forest Service. 1992. Malheur NF Mediated Agreement. Unpublished Letter. USDA Forest Service, Region 6, Malheur NF. John Day, OR.

USDA Forest Service. 1990. Forest-wide Standards. Malheur National Forest Plan. USDA Forest Service, Region 6, Malheur National Forest. John Day, OR. p. IV-40

USDA Forest Service. 1998. Watershed Protection and Management. Forest Service Manual. R6 Supplement 2500-98-1, Chapter 2520. USDA Forest Service, Region 6, Portland, OR. 7p.

USDA Forest Service. 2005. Pacific Northwest Region Invasive Plant Program Record of Decision. USDA Forest Service, Pacific Northwest Region. Portland, OR.

USDA Forest Service. 2013. Disturbed WEPP 2.0. Available [ONLINE] @ http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/wd/weppdist.pl [May 23, 2013]

Wardle, D. A., Bardgett, R. D., Klironomos, J. N., Setälä, H., Van der Putten, W. H. and Wall, D. H. 2004. Ecological linkages between aboveground and belowground biota. Science 304: 1629-1633

Williamson, J., and S. Harrison. 2002. Biotic and abiotic limits to the spread of exotic revegetation species. Ecological Applications. 12(1): 40-51

Wolfe, B.E. and J.N. Klironomos. 2005. Breaking new ground: soil communities and exotic plant invasion. Bioscience. 55(6): 477-487

Wood, Tamara. 2001. Herbicide Use in the Management of Roadside Vegetation, Western Oregon, 1999-2000: Effects on the Water Quality of Nearby Streams, USGS, Water Resources Investigations Report 01-4065.

Yu, Y.L., X. Wang, Y.M. Luo, J.F. Yang, J.Q. Yu, and D.F. Fan. 2005. Fungal degradation of metsulfuron-methyl in pure cultures and soil. Chemosphere. 60: 460-466

Zouhar, K., J.K. Smith, S. Sutherland, and M. Brooks. 2008. Wildland fire in ecosystems: fire and nonnative invasive plants. Gen. Tech. Rep. RMRS-GTR-42-vol. 6. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 355 p.

Glossary

Key words and definitions